Revive & Restore's Woolly Mammoth Revival Project [1]

By: Schnebly, Risa Aria Keywords: mammophant [2] de-extinction [3] gene modification [4]

In 2015, Revive & Restore [5] launched the Woolly Mammoth Revival Project with a goal of re-engineering a creature with genes [6] from the woolly mammoth and introducing it back into the tundra to combat climate change. Revive & Restore is a nonprofit in California that uses genome [7] editing technologies to enhance conservation efforts in sometimes controversial ways. In order to de-extinct the woolly mammoth, researchers theorize that they can manipulate the genome [7] of the Asian elephant, which is the mammoth's closest living evolutionary relative, to make it resemble the genome [7] of the extinct woolly mammoth. While their goal is to create a new elephant-mammoth hybrid species, or a mammophant, that looks and functions like the extinct woolly mammoth, critics have suggested researchers involved in the project have misled and exaggerated the process. As of 2021, researchers have not yet succeeded in their efforts to de-extinct the woolly mammoth, but have expressed that it may become a reality within a decade.

Researchers broadly define de-extinction as a method for reintroducing extinct species. However, the methods of de-extinction that researchers participating in the Woolly Mammoth Revival Project pursue would not lead to a perfect biological replica of a mammoth. The only chance to precisely recreate an extinct animal would be through cloning [8], a process of creating a genetically identical organism using the DNA of a host. DNA is the genetic information found in every living organism that carries the instructions an organism needs to develop, live, and reproduce. However, researchers cannot clone mammoths because cloning [8] requires living cells, whereas other genome [7] editing methods do not. Since one of the last species of mammoths went extinct around 4000 years ago, scientists are unable to acquire any living cells needed to clone the animal itself.

Because cloning [8] is not an option in the case of the woolly mammoth, Revive & Restore researchers are attempting to use genome [7] editing and engineering to make mammoth-like species instead of perfect replications of mammoths. Genome engineering is a technique that enables researchers to make changes to an organism's genome [7], which is its set of DNA. There are many technologies that equip scientists to edit an organism's genome [7] and change how it will develop and function. Researchers from the Woolly Mammoth Revival Project are experimenting with CRISPR-cas9, a genome [7] editing tool derived from bacteria that involves cutting out specific sequences of DNA and replacing them with other sequences. In the case of the de-extinction of the woolly mammoth, scientists would edit the Asian elephant genome [7] to make it more similar to the genome [7] from the woolly mammoth.

As the woolly mammoth's closest living relative, the Asian elephant is ninety-nine percent genetically identical to the mammoth without any genetic editing interventions. Genetic engineers can use CRISPR-cas9 to cut out and remove precise sequences of elephant DNA and replace them with the DNA sequences that make up specific genes [6] in the woolly mammoth's genome [7]. The genes [6] they add into the elephant genome [7] code for features that can make an elephant more mammoth-like, such as promoting the development of thicker layers of fat and longer hair. Researchers will not have created a biological woolly mammoth once an organism with that genome [7] develops. However, it would theoretically be a mammoth-like creature which some have researchers have called a mammophant. They speculate the organism will be able to survive in the Arctic, where woolly mammoths once lived to promote biodiversity in that area. Researchers at Revive & Restore expect the introduction of their hybrid species can help prevent the melting of permafrost, the thick layer of soil and bedrock that stays frozen year-round in the Arctic, thereby preventing the release of greenhouse gases.

Stewart Brand and Ryan Phelan founded Revive & Restore in 2012, launching its inception with a project designed to de-extinct the passenger pigeon, a species of bird that went extinct in the early twentieth century due to overhunting. The extinction of the passenger pigeon was one of the catalysts for the US conservation movement because it demonstrated how human action alone could entirely eradicate a species that was once extremely abundant. For Revive & Restore, the passenger pigeon was a model candidate for de-extinction not only because of its fame within the conservation movement, but also because the passenger pigeon was an important species in the forests of the eastern US. Its foraging and migration patterns helped to create areas within forests that allowed other species to populate.

Revive & Restore's next species of focus was the woolly mammoth, which was an important species in the Arctic, where the mammoth would trample plants and trees which would enable the arctic permafrost to remain frozen by exposing it the cold air. In 2012, Brand and Phelan hosted a meeting of international scientists interested in the project to discuss the feasibility of reintroducing the woolly mammoth, or a species very similar. Two of the project's key figures, scientists George Church [9] and Sergey Zimov, met at that meeting and discussed its practicality. Church, a professor of genetics at Harvard Medical School [10] in Boston, Massachusetts, had the scientific expertise needed to engineer a mammophant. Zimov, a researcher of ecology from

Russia, could provide a place the mammophants could live, and suggested the potential role of the mammophant in combatting global warming.

In 1996, Zimov founded Pleistocene Park, a fifty square mile wide nature reserve in the remote Siberian Arctic where mammophants may eventually roam. Some of the goals of Pleistocene Park include restoring the area's ecosystem, protect the permafrost, and prevent further global warming. Zimov had already reintroduced large grazing animals into the park to replace the wildlife that existed in that region in the late Pleistocene era, which was a span in Earth's history that ended about 12,000 years ago. Zimov believes that reintroducing large species like mammophants could mitigate the effects of global warming in the Arctic by helping to prevent the thawing of arctic permafrost.

During the late Pleistocene era, mammoths and other large animals trampled and scraped snow away from the ground, exposing the permafrost to cold winter air that could penetrate the ground and keep the deep layers of the permafrost frozen. Without the activity from large animals, there is nothing to disturb the snow that covers the ground, which means the colder air cannot reach and freeze the permafrost during the winter. That means that the permafrost can melt more easily upon the arrival of seasonal warm weather, especially as global temperatures rise due to global warming. When arctic permafrost thaws, it can release greenhouse gases that have been trapped within it for centuries. Those greenhouse gases can trap heat inside the earth's atmosphere and researchers predict its impact will be greater than any other factor contributing to global warming. However, according to Zimov, the reintroduction of large grazing animals into Pleistocene Park has already seemed to help keep deeper layers of the permafrost frozen. After Church visited Pleistocene Park himself in 2015, Church and Zimov launched the Woolly Mammoth Revival Project with Revive & Restore.

Before genetic engineers can begin to add mammoth genes [6] into the elephant genome [7], they first have to identify which genes [6] are the most critically involved in the features they hope to emulate. The mammoth genome [7] was first sequenced in 2008 by a team of biologists at Penn State University in State College, Pennsylvania. The team used samples of mammoth hair found in two mammoth specimens buried in the Siberian permafrost, one that was 20,000 years old and another that was 60,000 years old. Though most DNA specimens that old would be too degraded for scientists to sequence, the mammoths had been frozen and preserved in the Siberian permafrost. However, the mammoth's DNA sequence does not specifically communicate the associated genes [6]. To determine those genes [6], researchers have tested and compared the sequences of the woolly mammoth to those of the Asian elephant.

Scientists can reprogram the cells they edit to become different kinds of cells in the body, such as red blood cells, hair cells, or tissue cells. By pushing the edited reprogrammed cells to develop, the team can then see what the outcome of the genome [7] edits they make will be. For example, if the researchers splice in a gene meant to give the elephant longer, mammoth-like hair, they can then push the group of cells they edited to develop into actual hair cells through genetic engineering without ever having to create an actual organism. They can then see what the creature's hair will actually look and feel like, how long it will grow, and how thick it will be, among many other things. Then researchers can see whether the edits they made will really make the elephant more cold-resistant or not. After testing to confirm that the gene edits have the outcome the researchers wanted, the researchers can then combine all their successful edits into one genome [7] sequence that they will use to create an animal.

As of 2020, Church continued to lead one of the teams working to identify the important genes [6] within the woolly mammoth genome [7] with the use of CRISPR-cas9. One of the most recent updates from Church's lab in 2017 announced that they had successfully located forty-five genes [6] that code for traits to make the hybrid more resistant to cold weather. Though there are several thousand genetic differences between the genome [7] of the mammoth and Asian elephant, Church has hypothesized in some interviews that his team may only need to splice in fifty of the mammoth genes [6] to create a mammophant capable of surviving in the Arctic.

Out of concern for animal welfare, Church and his team have stated they plan to avoid forcing Asian elephants to act as a surrogate [11] for the mammophant by growing the mammophant embryo in an artificial womb [12] outside of the body instead. Additionally, the team can test the physical effects of changing and combining the genomes without having to produce an actual animal. Asian elephants are an endangered species as of 2020, so scientists have used genome [7] editing technologies for early investigations into proving the feasibility of the concept. Additionally, critics such as Matthew Cobb, a professor of zoology at the University of Manchester in Manchester, England, doubt that scientists can achieve the capability to produce a functional artificial womb [12] within the next decade. Cobb explained that an artificial womb [12] would deprive a fetus [13] from many important pre-birth interactions with its gestational carrier that help the fetus [13] to properly develop. However, Church and his lab have conducted early experiments attempting to grow mouse [14] embryos *ex vivo*, or out of a uterus [15], rather than *in vivo* [16], meaning in a uterus [15], and have suggested the technology will become possible within the next decade.

Even if the technology may soon be feasible, many critics question whether we should be trying to de-extinct the mammoth at all. For example, David Ehrenfeld, a professor of biology at Rutgers University in Camden, New Jersey, has raised concerns that the mammophants may not be able to survive in the Arctic because they are genetically different from the extinct mammoths and will not be able to learn survival skills without a herd. He suggests those factors could also lead the mammophants to behave unpredictably in their environment and possibly even cause more destruction than help. To avoid that problem, Revive & Restore has stated plans to raise eventual mammophants with captive Asian elephant families in zoos who may teach them survival and herding behaviors so the mammophants can one day form herds of their own.

Additionally, many ethicists have expressed concern over de-extinction being an immoral endeavor. De-extinction, if successful, may eventually undermine the conservation movement by making extinction seem like less of a problem. If extinction suddenly seems reversible, the public may feel less responsible for behaviors and actions that contribute global warming and biodiversity loss. For example, Ben Minteer, a professor of environmental ethics at Arizona State University in Tempe, Arizona, has noted that the premise of de-extinction may teach people that technology alone can reinforce the idea that human will remain unaccountable for changing their behaviors to prevent such damage from occurring in the first place. Other conservationists like Stuart Pimm, a professor of conservation ecology at Duke University in Durham, North Carolina, worry that the time, money, and effort dedicated to de-extinction efforts like the Woolly Mammoth Revival Project could divert important funds dedicated to protecting the many endangered species and ecosystems still around today. Additionally, journalists have suggested the notion of the topic entirely became manipulated with aggrandized and sensationalist headlines without regard to the restrictions and hindrances scientists will need to overcome before making it a reality.

As of 2021, the Woolly Mammoth Revival Project was still in the process of revising the elephantgenome [7]. Whether or not the project is ultimately successful, the scientific and public discussion on de-extinction has prompted questions that consider how far humans [17] should be allowed to interfere with nature. Althoughhumans [17] may be responsible for behaviors that have led to global warming, the risks and uncertainty surrounding de-extinction may outweigh the benefits of correcting such mistakes.

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Subject

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